Chapter 6
Soil Washing/Solvent Extraction

6-1. General

The methods of soil washing and solvent extraction, their applications, and resulting waste streams are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

6-2. Technology Description

a. Soil Washing.

(1) Process.
Soil washing typically uses water as the solvent (sometimes with wash-improving additives) to extract, desorb, and dissolve contaminants, particularly hydrophilic contaminants. It is also used to sort and separate the contaminated solids by size. Soil washing removes contaminants from soils by dissolving or suspending them in an aqueous wash solution or by concentrating them into a smaller volume of soils, typically the "fines," as this fraction has the highest specific surface area (surface area/volume or mass).

In the soil washing process (Figure 6-1), contaminated soil is screened and homogenized prior to being fed into the washing apparatus. Extraction agents (e.g., surfactants or pH modifiers such as hydrochloric acid) and makeup water are added to the soil. After sufficient mixing, remediated soils are separated from the water. Concentration of contaminants into a smaller volume of soil begins with the use of a "grizzly" to separate out large rocks and continues with various screening and controlled rate-settling processes. Oversized rejects are discarded and the remaining solids washed to separate fine (small) clay and silt particles from the coarser sand and gravel particles.

The success of this technology is based on the principle that most organic and inorganic contaminants preferentially bind, either chemically or physically, to clay, silt, and organic soil particles. The smallest particles have a higher specific surface area, thus increasing their sorbed concentrations relative to volume or weight. The silt and clay are attached to sand and gravel by physical processes such as compaction and adhesion. For heavy metal compounds (such as lead or radium oxides), gravity separation can separate low- and high-specific gravity particles. Adherent contaminant films can be removed from coarser particles by attrition scrubbing. At the end of the process, the remediated solids can be returned to the site or disposed of off site. If the soil does not meet the agreed remediation criteria after washing, the process can be followed by additional treatment of the solids.

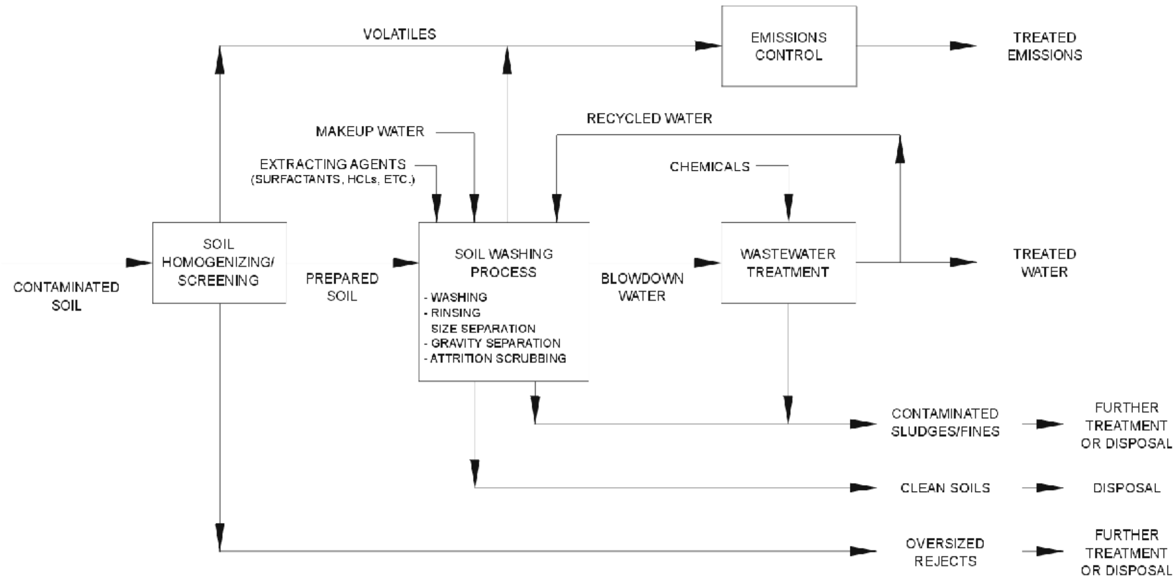

FIGURE 6-1. TYPICAL PROCESS FOR SOIL WASHING

(2) Applications.
Soil washing has been applied to the remediation of semi-volatile compounds, fuels, and inorganics, such as heavy metals and radionuclides. Under certain circumstances, the technology can be applied to volatile compounds and pesticides. Removal of fine soil particles (e.g., silts and clays) from the washing fluid may require the addition of polymeric materials such as flocculants.

(3) Resulting Waste Streams.
This process can produce up to five streams that may require additional handling or treatment:

- Volatile emissions from soil homogenization/screening (require additional treatment).
- Oversized rejects from soil preparation (require additional handling).
- Wastewater (requires additional treatment).
- Contaminated sludge/fines (require additional treatment).
- Solids (may require additional treatment).

The wash water is treated in a wastewater treatment plant and, whenever possible, treated water is recycled back into the washing apparatus.

b. Solvent Extraction.

(1) Process.

Solvent extraction uses a chemical solvent (usually organic) to extract, desorb, and dissolve contaminants. As illustrated in Figure 6-2, contaminated soil, sludge, or sediments are excavated, sized, and screened prior to the extraction process. The homogenized solids are mixed with solvents such as pentane, methyl ethyl ketone, or water-based solvents that extract much of the contaminants. The treated soil matrix is separated from the contaminated solvent and returned to the site after having met remediation cleanup criteria, including solvent concentrations. If the soil does not meet the agreed criteria, solvent extraction can be combined with other technologies to complete treatment. In the ideal version of the process, the contaminants are removed from the solvent and clean solvent is recycled to the extractor.

The solvent should be selected based on the materials to be extracted and other practical characteristics (e.g., ease of recovery and reuse). The toxicity of the solvent is an important consideration if traces of solvent remain in the treated soils. Most solvent extraction processes use hydrophobic solvents such as pentane since most of the contaminants needing to be specifically extracted are hydrophobic. Hydrophilic contaminants may not be effectively removed by the usual organic solvent extractant, and the presence of detergents and emulsifiers can reduce the effectiveness of the technology. For hydrophilic contaminants, water- or amended-water-based solvents should be used as the solvent. The organic solvent technology is generally not used for extracting inorganics (e.g., acids, bases, salts, or heavy metals), and inorganics usually do not have a detrimental effect on the extraction process.

(2) Applications.

Solvent extraction has proven effective in treating sediments, sludges, and soils containing high concentrations of primarily organic contaminants, such as polychlorinated biphenyls (PCBs), VOCs, halogenated solvents, and petroleum hydrocarbon wastes. Organically bound metals (e.g., alkyl lead or tin compounds) can be extracted along with the target organic contaminants, which may result in restricted handling of the residuals.

(3) Resulting Waste Streams.

The process can produce up to five streams that may require additional treatment or special handling:

- Emissions from waste preparation and solvent handling (requires additional treatment).
- Oversized rejects from waste preparation (requires additional treatment or handling).
- Water from moisture content of solids (requires additional handling and possible treatment).
- Concentrated contaminants (requires additional treatment).
- Solids (may require additional treatment).

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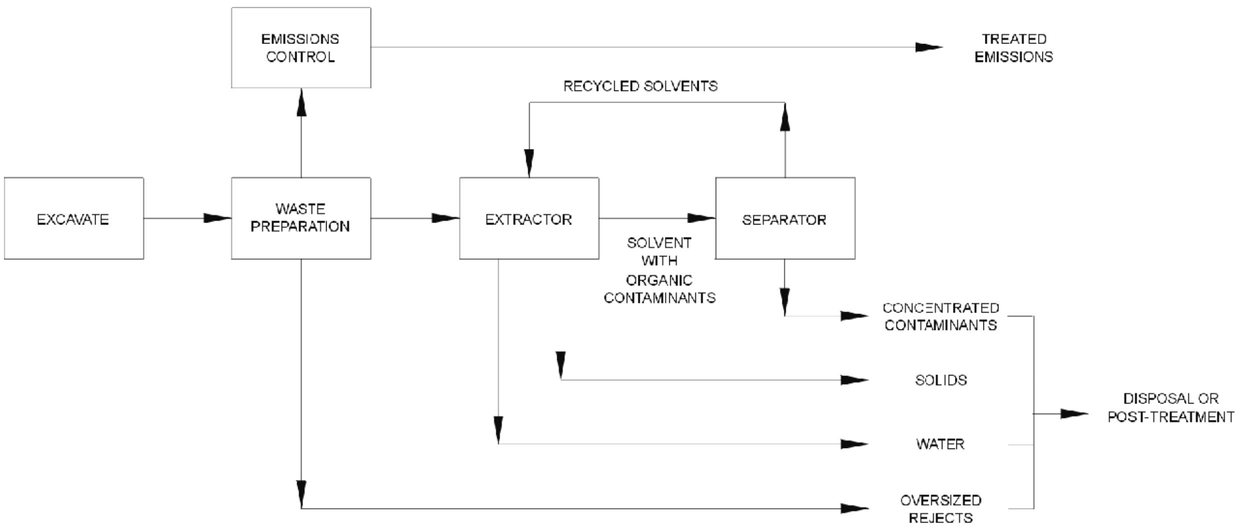

FIGURE 6-2. TYPICAL PROCESS FLOW FOR SOLVENT EXTRACTION

6-3. Hazard Analysis

Principal unique hazards associated with soil washing/solvent extraction, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Heat Stress.*
Description. Workers may be exposed to elevated temperatures, especially during the excavation phase of the treatment process owing to excessive seasonal temperature or operation of process equipment, or both. The exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in the signs and symptoms of heat stress.
- Use the Buddy System and provide easy access to water.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun

hats should not be worn around moving parts or close to equipment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.

- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.

CONTROL POINT: Design, Operations, Maintenance

(2) *Equipment Hazards.*
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. This equipment may also cause a noise hazard.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection around operating equipment.

CONTROL POINT: Construction, Operations

(3) *Fire and Explosion Hazards.*
Description. During excavation into soils saturated with flammable or combustible materials, fire or explosion hazards may exist. Under unusual or extraordinary conditions, the bucket of a backhoe or the blade of a crawler may cause a spark during contact with rocks, buried metal, or other objects and ignite a flammable vapor that may be created.

Control. Controls for fire and explosion hazards include:

- Train the operators in the hazards of excavating into or through flammable liquids or materials.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation isolation and equipment shutdown procedures.
- Equip the backhoe with a non-sparking bucket or blade when highly flammable excavation materials are suspected.
- Wet the active work area with water periodically.

CONTROL POINT: Design, Operations

(4) *Unguarded Moving Equipment.*
Description. The movement of soil from the excavation area to the treatment unit by a conveyor may create pinch-point hazards from unguarded rollers. Workers' clothing may become entangled with the rollers, causing injury or death.

Control. Controls for minimizing exposure to moving equipment include:

- Use guards for conveyor belts, rollers, and associated equipment to prevent accidental contact.
- Train workers in identifying potential pinch points.
- Disallow the wearing of loose-fitting clothing.

CONTROL POINT: Design

(5) *Fire and Explosion Hazards (Crushing Soils).*
Description. Fire and explosion hazards may exist as soils containing flammable materials are crushed and sized or screened for treatment. As aggregate soils are crushed, sufficient heat may be generated to ignite vapors that have volatilized from the soil. Noise and vibration may also be present during equipment operation. Workers may also be exposed to flying projectiles as a result of the crushing/grinding operation.

Control. Controls for fire and explosion hazards during soil crushing include:

- Train the operators in the hazards of excavating, crushing, and screening soils that are sufficiently contaminated or saturated with flammable liquids or materials. Incorporate in the training on ignition sources any potential for the creation of static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in soil handling/processing system isolation and equipment shutdown procedures.
- Reduce the potential for a fire or explosion with periodic application of water.
- Install equipment on vibration dampening bushings to reduce vibration and noise.
- Use baffles or sound deflecting/absorbing walls between the source and the operator to control noise, and use hearing protection.
- Wear safety glasses with side shields to help prevent eye injuries from projectiles during operation of soil sizing and screening equipment.

CONTROL POINT: Construction, Operations

(6) *Fire and Explosion Hazards (Distillation).*
Description. Fire and explosion hazards may exist during distillation of solvents used in the extraction process. Over-pressurization may result in rupture of the vessel. The resulting release of flammable solvent may pose a fire or explosion hazard.

Control. Controls to prevent over-pressurization of distillation and solvent delivery systems include:

- Train the operators in the hazards of distilling flammable solvents used for the extraction process. Incorporate in the training on ignition sources any potential for the creation of static electricity in the distillation process.
- Perform a Process Hazard Analysis (PHA) prior to startup and correct all deficiencies found.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency distillation system isolation and shutdown procedures.
- Use pressure relief valves and hazard warning alarms.

CONTROL POINT: Design

(7) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.
- Allow only trained and authorized workers to operate the steam pressure equipment.

CONTROL POINT: Construction, Operations, Maintenance

(8) *Respirable Quartz Hazard*.
Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422 (R2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with N, R or P100 particulate air filters.
- Train the workers in the potential hazards of exposure to crystalline silica inhalation hazards.

CONTROL POINT: Design, Construction, Operations

(9) *Confined-Space Hazards*.
Description. Workers may be exposed to confined-space hazards during entry into mixing/reaction vessels for maintenance. Confined space may expose workers to toxic atmospheric hazards or to hazards associated with oxygen deficiency.

- *Control.* Controls for confined-space hazards include:
- Train workers in confined space hazards and on safety procedures to employ in confined space entry.
- Design the confined space to maximize natural ventilation.
- Develop a pre-entry confined space permit. Implement a confined-space entry program to assess hazards, including air testing the space interior both prior to and throughout the work planned (see 29 CFR 1910.146).
- If the space is filled with flammable vapors, eliminate all potential sources of ignition prior to and during occupancy.
- Require testing of the atmosphere prior to entry into the reaction or mixing vessels, or other confined spaces.
- Ventilate the space prior to and during entry and use supplied air and confined space monitoring techniques to eliminate the hazards (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations.

CONTROL POINT: Design, Operations, Maintenance

(10) *Electrical Hazards*.
Description. Operation of temporary and permanent electrical equipment, such as lights, generators, and soil washing/solvent extraction system components may cause electrical hazards.

Control. Controls for electrical hazards include:
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Verify that all controls, wiring, and equipment conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Use grounded equipment or equipment with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) *Emergency Wash Equipment Hazards*.

Description. Emergency shower/eyewash equipment required by 29 CFR 1910.151 is not always equipped with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing and use.

Control. Controls for wash equipment hazards include:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eyewash equipment with accompanying functional drains to isolate and collect the shower/eyewash water from unprotected electrical equipment and walking surfaces that may be hazardous when wet.

CONTROL POINT: Design

(12) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) *Extracting Agents and Solvents.*
Description. Workers may be exposed to VOC emissions from either extracting agents (surfactants and concentrated acids), solvents used in the solvent extraction process, or to wastes in the extraction/washing process. Examples of solvents include methyl ethyl ketone, pentane, and citric acid derivatives.

Control. Controls for chemical exposure include:

- Add chemicals to the system under closed or properly ventilated conditions.
- Use respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges or air-supplied respirator depending on the existence of adequate warning properties) to control inhalation exposures.
- Assess the exposure by exposure monitoring to determine the type of respirator for the particular application.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Chemical Release from System Malfunction.*
Description. During system failure, workers may be exposed to either solvents or extraction agents if the system experiences a release from over-pressurization or other malfunction.

Control. A control to prevent system chemical release includes:

- Use a system designed with redundant safety features, including automatic warning systems, to prevent a release of chemicals from over-pressurization or other malfunction.

CONTROL POINT: Design

(3) *Chemical Exposure from Precipitation Chemicals or Sludge.*
Description. During the process of treating water from the operation, workers may be exposed to chemical hazards from acidic or caustic precipitation chemicals or to the sludge generated from the process. Exposure may be through inhalation/dermal/ingestion routes. The sludge may contain heavy metals, including lead, or organic compounds such as fuels.

Control. Controls to prevent chemical exposure include:

- Design a closed-feed system for the addition of precipitation chemicals as well as for sludge handling and removal.
- Use less toxic precipitation agents.
- Use personal protective equipment (PPE): nitrile gloves for dermal protection from fuels and an air-purifying respirator with combination N, R, or P100 particulate air filter/organic vapor cartridges for control of inhalation hazards.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radioactive Material.
Description. Radiological materials may be segregated in the soil washing process, and naturally occurring radioactive material (NORM) may be present in soils, sludge, and groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion.

Control. Controls for radioactive materials include:

- Test soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found. Consultation should result in determination of exposure potential, any necessary controls, or required PPE.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

Biological Contaminants.
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during the soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp*., *Histoplasma sp*., and *Mycobacterium sp*. if contaminated dusts become airborne.

Control. Controls for biological contaminants include:

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and use portable surface covers.
- Use proper types of PPE: an air-purifying respirator with N, R or P100 or N, R or P95 particulate air filter approved for microbial inhalation hazards.
- Offer frequent health and safety awareness meetings, use experienced workers, decontamination stations, and standard personal hygiene procedures.

CONTROL POINT: Design, Construction, Operations